

LCA Case Studies

Application of Life Cycle Assessment to the LCA Case Studies Single Superphosphate Production

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Abstract

Goal, Scope and Background. There is a competition between wet and thermal routes for phosphate fertilizers manufacture. In the Brazilian case, the thermal route is represented by thermophosphate. This fertilizer is considered the most adequate one for Brazilian agricultural conditions; its main restriction is the intensive consumption of energy necessary for its production. The wet route uses sulfuric acid to directly produce the single superphosphate (SSP) or the intermediate phosphoric acid, which will be used to result in triple superphosphate (TSP) and ammonium phosphate production. The main restriction of the wet route is the large amount of phosphogypsum generated in phosphoric acid production. Envisaged is an environmental comparison of both routes using LCA methodology. This paper presents the LCA for SSP production. The goal of the study is to establish the Environmental Profile of this fertilizer. Eight impact categories were selected for the study. The system boundaries was defined for a 'cradle to gate' approach, including extraction of natural resources, intermediate products, and production.

The SSP System. The SSP system (single superphosphate) comprises the stages of mining and concentration of the phosphate rock, elemental sulfur extraction, production of sulfuric acid, and manufacture of single superphosphate.

SSP LCI. The LCI was performed considering the production of 1.0 ton of SSP (single superphosphate) as a Functional Unit. The data collected were developed for different producing companies, all of them located in the same regional area. Allocation criteria of energy and mass were applied to the production of sulfuric acid and manufacture of single superphosphate. The transportation step included either the transport of the mined phosphated rock to the concentration plant or the transport of the phosphate concentrate to the SSP unit.

Conclusion, Recommendation and Perspective. The accomplishment of an LCA to SSP production identified the GWP and EP as its meaningful environmental impacts. In reference to global warming, the transportation step was the greatest contributor agent, while the losses of PO_4^- from the SSP manufacturing were the main cause of EP. The most important contribution in terms of water consumption was observed in the concentration step. Finally, the self sufficiency of the sulfuric acid production in energetic terms must be highlighted.

The knowledge of the environmental profile of fertilizers is necessary to support LCA studies of agricultural products, a relevant raw material source for many industrial sectors. The method used here may be important for modelling other LCA fertilizer studies. As most of the agricultural raw materials are transferred among different countries, comparisons of the environmental profiles of fertilizers in developed and developing countries are needed.

Keywords: Life cycle assessment (LCA); life cycle inventory (LCI); single superphosphate manufacture; allocation LCA; fertilizer; phosphate fertilizer; sulfuric acid production, LCA; sulfuric acid, environmental impacts; Brazil; Brazilian industry

Introduction

The agribusiness is the main sustainer of the Brazilian economy. This activity turns over about US\$ 310 million nowadays – 40% of the GDP – still being responsible for more than 17 million of employment (EMBRAPA 1999). In this frame, a significant effort has been developed towards the increase of agricultural productivity, where fertilizers play an important role.

Considering the large experience in fertilizer technology achieved at the Chemical Engineering Department of the University of São Paulo, its Group of Pollution Prevention – GP2 – decided to develop an environmental comparison between wet and thermic routes of phosphate fertilizer manufacture, using LCA.

Thermophosphate – phosphate fertilizer obtained in the thermal route – is considered the most adequate one for the Brazilian agricultural conditions. Despite this fact, it shares only 2% of the consumption market. The main allegation is the high amount of energy necessary for its production.

The wet route consists of the use of sulfuric acid to directly produce single superphosphate or the intermediate phosphoric acid, and then triple superphosphate and ammonium phosphates. The main restrictions to this route are the need of sulfur – Brazil imports 85% of its need – and the large amount of phosphogypsum generated in phosphoric acid production; this residue is a potential threat to the environment.

The environmental comparison of the routes will comprise the development of LCA studies for thermophosphate, triple superphosphate (TSP) and single superphosphate (SSP). This paper presents the LCA of SSP.

1 Description of SSP System

The SSP system comprises the steps of mining and concentration of the phosphate rock, production of sulfuric acid – H_2SO_4 , and manufacture of SSP.

The mining of the phosphate rock generally occurs in an open area and sometimes it is necessary to use explosives. The run of mine phosphate rock is crushed, classified and homogenized before going to the concentration step (Silva 1982).

According to Leal (1991), the concentration step consists in the increasing of phosphoric ore content by the removal of

accessory ores. The main operations in this step are milling, demagnetization, conditioning and flotation. The wet milling is made in iron bars or ball mills. The suspension resultant from this operation goes to demagnetization, where the magnetite grains existing in the rock are removed through contact with a magnetic cylinder. The conditioning consists in the addition of depressor and collector agents that allows the separation of apatite and accessory ores. This separation is achieved by flotation with air bubbling. The product of the concentration – phosphate concentrate – contains between 32% and 36% of phosphorus pentoxide – P_2O_5 .

The sulfuric acid production is initiated by the fusion of the elementary sulfur followed by the filtration of the liquid sulfur. The solid waste from this operation – known as spent sulfur – is discharged from the process. The fused sulfur is burned in a furnace generating sulfurous anhydride. In the presence of the catalyst vanadium pentoxide, the sulfurous anhydride is oxidized to sulfuric anhydride. Finally, the

sulfuric anhydride is hydrolyzed by water absorption from a concentrated solution of sulfuric acid.

Periodically, part of the vanadium pentoxide must be substituted and the discharged catalyst is a hazardous waste.

The sulfuric acid production process is characterized by being able to recover energy as steam. The mass relationship estimated between the amounts of steam and sulfuric acid generated in the process is 1.1 to 1.2.

The manufacture of SSP consists of the attack of the phosphate concentrate by the sulfuric acid. The fluorine content of the phosphate rock is recovered during this step as the coproduct fluorsilicate (Cekinski 1990). Initially, the ground phosphate rock is mixed with sulfuric acid; the mixture goes to a conveyor where it solidifies in about 20 minutes. The material discharged from the conveyor is stored in a pile for about one week for the final curing (Silva 1982). Fig. 1 shows the SSP manufacturing steps.

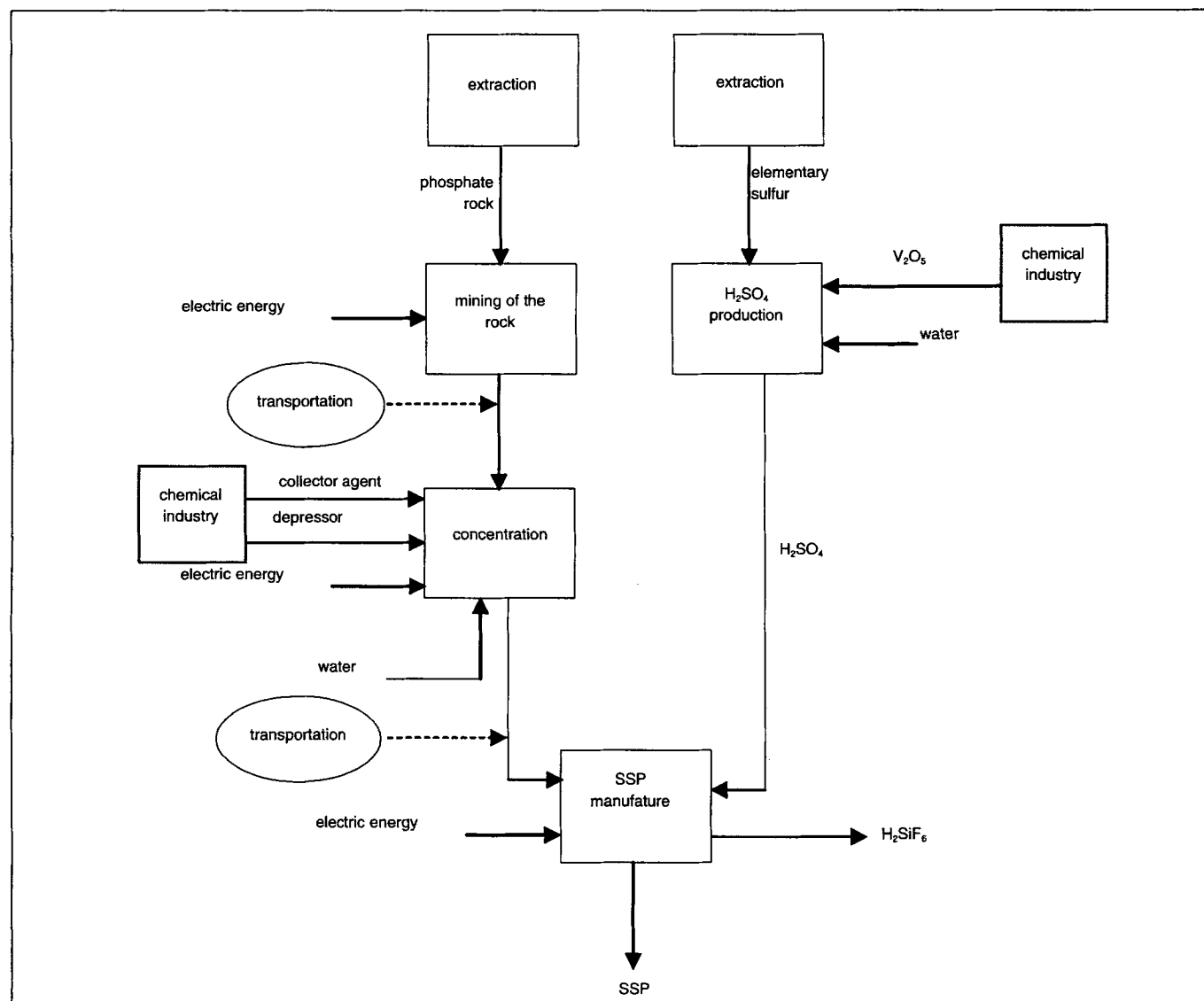


Fig. 1: Life cycle process tree of SSP production

2 SSP Life Cycle Assessment

2.1 Definition of goal and scope

The objectives of this study are the development of the environmental profile of SSP and the identification of opportunities of its environmental performance improvement.

The scope definition was fulfilled according to the objectives and comprised boundaries, functional unit and criteria of exclusion of environmental and allocation aspects.

The approach known as 'from the cradle to the gate' was adopted so that the use and final disposal of the fertilizer was not included. The life cycle boundaries included the steps of phosphate rock mining and concentration, sulfuric acid production, SSP manufacture and the transport.

It was not included in the study concerning the operations of extraction and transport of elemental sulfur, once most of it is imported by the Brazilian manufacturers of sulfuric acid. It was also not included in the manufacturing steps for conditioning agents and catalyst.

The functional unit was defined as 1 ton of SSP containing 18.2% of P_2O_5 .

As suggested by Vigon (1993), it was defined that environmental aspects, whose flows corresponded to a percentage of contribution inferior to 1.0% of the total of inlet and outlet for each process unit, would be excluded. Exceptions were made for the cases of the atmospheric release of

sulfurous anhydride and the mist of sulfuric anhydride, as well as for the generation of spent sulfur and of vanadium pentoxide (V_2O_5) catalyst, once their potential environmental impacts would be significant.

For the allocation the use of mass criteria according Curran (1996) was defined.

2.2 Life cycle inventory

The life cycle inventory was elaborated upon based on data collected from different SSP producing companies, all of them located in the same regional area. The results of this survey are presented in Table 1. The data shown in Table 1 are the consolidated values of the environmental aspects identified in the inventory. This means that the values are already converted to the functional unit and the allocation factors for sulfuric acid and energy, and for SSP and fluorsilicate, are already applied.

The electrical energy consumption from the mining step is pointed out in Table 1 of the LCI, and corresponds to the sum of the amounts spent for the operations of extraction, crushing, homogenization, recrushing and screening. The particulate emission results of these same operations presented a contribution percentage inferior to 1.0% of the total withdrawal of this step, and were therefore not considered. It was not possible to determine the generation of particulate matter produced during the extraction from the environment by the use of dynamite.

Table 1: Consolidated values of environmental aspects associated with the production of 1 ton of SSP

Environmental Aspects	Mining	Concentration	Production of H_2SO_4	Production of SSP	Transport
Energy Inputs (MJ)					
Electrical energy	33.0	307	–	410	–
Fossil fuels	–	–	–	–	298
Material Inputs (kg)					
Water	537	7,477	204	1,425	–
Atmospheric Emissions (kg)					
CO	–	–	–	–	0.02
CxHy	–	–	–	–	0.061
NO _x	–	–	–	–	0.567
SO ₂	–	–	0.484	–	0.042
Particulate Matter	–	–	–	–	0.037
CO ₂	–	–	–	–	38.3
SO ₃ mist	–	–	0.009	–	–
HF	–	–	–	0.011	–
Solid Waste (kg)					
Magnetite	–	760	–	–	–
Mud	–	672	–	–	–
Non-apatite waste	–	2,301	–	–	–
Spent catalyst	–	–	9.09	–	–
Liquid Effluent (kg)					
Dissolved solids	–	7,705	–	–	–
Phosphate	–	–	–	1.99	–

Table 2: Water consumption in concentration

Inlet		Outlet	
Flow	kg water ton SSP (18.2%)	Flow	kg water ton SSP (18.2%)
Water in the phosphate rock	537	Water with magnetite	673
Clean water	7,477	Water with mud	5,881
		Water with non-apatitic ore	1,151
		Water with phosphate conc.	309
Total	8,014	Total	8,014

The concentration unit is the greatest water consumer of all the systems in the study. This fact can be proven by the data presented in Table 2.

According to Table 2, the water balance in the concentration step pointed out a consumption of clean water of 7.5 m³/ton SSP. In the same way, the generation of liquid effluents – composed by dissolved solids of magnetite, mud and non-apatitic ore – achieve almost the same amount: 7.7 m³/ton SSP. The solid wastes generated in the concentration correspond to the accessory ore amounts, which were taken by the flow of water which was not recovered. The collector and depressor agents are non-toxic salts, and their contributions are smaller than the standard established to the study. In this frame, the environmental impacts caused by these substances were unconsidered by the study.

As mentioned before, the production in the sulfuric acid process is self sufficient in terms of electrical energy. This means that the steam generated as a coproduct is enough to fulfill the whole demand of this type of energy for the processing, and it is unnecessary for the use of complementary sources.

Table 3 presents the energetic balance of the sulfuric acid production, as proposed by Sander (1984), for the North American companies, whose productive processes are similar to those performed by the Brazilian industries in the fertilizer sector.

According to Table 3, 97% of all the energy entering in the processing unit is obtained from the exothermic reactions of the transformation of elementary sulfur into sulfuric acid. About 60% of this total can be recovered as saturated steam at high temperature, which is converted to electrical energy in a turbine, in a typical process of co-generation. The electrical energy produced is enough not only to fulfill the demand of the own installation, but also to fulfill the needs of other productive units. Part of the unrecovered energy remains in the sulfuric acid produced, and the rest is dissipated in the envi-

ronment as steam. Considering the fact that the superheated steam is a coproduct of the sulfuric acid production process – which, according to Bruno (1985), is generated at a rate of 1.1 ton/ton of sulfuric acid – the first allocation of environmental charges of the study was performed here. The water consumption in the production of sulfuric acid is relative to the production of superheated steam.

The value pointed out in Table 1 refers to the amount of water that feeds the boiler, installed with the objective of recovering the heat aggregated to the produced gases in the converter.

In terms of atmospheric emissions, gases of SO₂ and SO₃ are released into the atmosphere during the production of sulfuric acid. Although the percentage contributions from these flows were inferior to 1.0% of the total that leaves the process unit, the potential environmental impact associated with them suggested their inclusion in the inventory. In the same way, the solid wastes, the disposal of sulfur waste and of the catalyst were also highlighted.

For the electrical energy consumption in the SSP manufacture, 410 MJ/ton SSP was adopted, as suggested by the IFDC (1982). The water consumption of this step refers to the dilution of the sulfuric acid solution to 70% of concentration, its cooling to 65–70°C and washing of gases of hydrofluoric acid – HF – generated in the reactor during the SSP production.

In this step, the coproduct hexafluorsilicic acid is generated, and the corresponding allocation is performed. The residual amount of HF, not washed in the washing tower; similar to sulfur oxides and vanadium pentoxide catalyst, was included in the inventory. In terms of liquid effluents, the PO₄³⁻ rate of generation, measured in the end of the effluent treatment in the SSP plant, is highlighted. As in the previous case, this environmental aspect was also included in the LCI, due to the impacts caused upon the environment.

Table 3: Energetic balance of the H₂SO₄ production

Inlet		Outlet	
Origin	(%)	Origin	(%)
Exothermic reaction: S → H ₂ SO ₄	97.0	Steam (40kgf/cm ² ; 450°C)	60.0
Electrical energy	3.0	Energy lost: refrigeration circuit	37.0
		Atmospheric emission	2.5
		Sulfuric acid	0.5

Source: Adapted from Sander (1984)

2.3 Transportation

The transportation was considered in two stages. The first refers to the transport of the mined phosphated rock to the concentration plant in a 5 km unpaved road. The second stage was the transport of the phosphate concentrate to the SSP plant along a 1,100 km paved road. In both cases, trucks with a capacity of 27.2 ton of load, and diesel oil consumption of 2.2 km/L were considered.

3 Impact evaluation

The impact categories considered in the classification step of impact evaluation were:

- non-renewable energy sources depletion (NRES)
- water consumption (WC)
- global warming potential (GWP)
- photochemical oxidant creation potential (POCP)
- acidification potential (AP)
- eutrophication (or nutrification) potential (EP)
- human toxicity potential (HTP)
- solid waste generation potential (SWGP)

The characterization step of the methodology was developed according to UNEP (1996). For natural resources consumption, it the values of the inventory were used directly, with no characterization. The Environmental Profile of SSP, expressed in terms of relative contribution of its life cycle steps to the different impact categories, is presented in Fig. 2.

The main environmental impact associated to the mining of the phosphate rock was the energy consumption, 33 MJ/ton SSP – corresponding to 3.2% of the energetic demand of the process as a whole. From this total, 84.8% were used in the operations of primary crushing, classification and homogenization.

In the concentration stage, the LCA study identified environmental impacts related to NRES and WC, as well as SWGP. Regarding the energy, this stage consumes 307 MJ/ton, corresponding to 29.3% of the total of the system; phosphate rock milling – the largest energy consumer operation – shares 85.4% of this amount.

On the other hand, the WC of the concentration achieved 7,477 kg/ton, corresponding to 77.5% of the system demand. This amount refers to the clean water introduced in the process to replace the losses as liquid effluents, and the incorporation of water to the phosphate concentrate produced.

The SWGP – 3.7 ton per ton of SSP – 99.8% of the total amount generated in the system.

The inadequate disposal of these accessory minerals increases the significant impact of area degradation and use.

The relevant impacts associated with sulfuric acid production are SWGP, AP and HTP. The SWGP is associated with the disposal of spent vanadium pentoxide catalyst. Despite this amount being about 0.2% of the total solid waste from the system, it should be considered due to the fact that vanadium is a heavy metal with a meaningful contribution to earth ecotoxicity potential.

In terms of AP, this stage has a contribution of 52%, due to the sulfuric oxide emissions. These emissions are also responsible for HTP. Even though the relative contribution to this environmental impact was 54% – motivated by the release of SO₂ – its amount was only 0.5 kg of the corporeal mass exposed to the acceptable limit of 1.0 kg of this substance.

The SSP manufacturing causes environmental impacts in terms of NRES and WC, as well as AP and EP. The average energy consumption for the production of 1.0 ton of SSP was 410 MJ – 39.1% of the energetic demand of the system. Regarding the WC, this stage amounts 1,425 m³/ton in operations of dilution and cooling the sulfuric acid solution and gas washing. On the other hand, its contribution to AP is less meaningful, around 2%. The responsible agent for this environmental impact is the residual release of HF not retained by the system of gas washing. Finally, for EP impacts, the average release for the production of 1.0 ton of SSP is of 20.8 kg NO₃⁻(eq), and refers to the residual PO₄³⁻ in the liquid effluent after treatment.

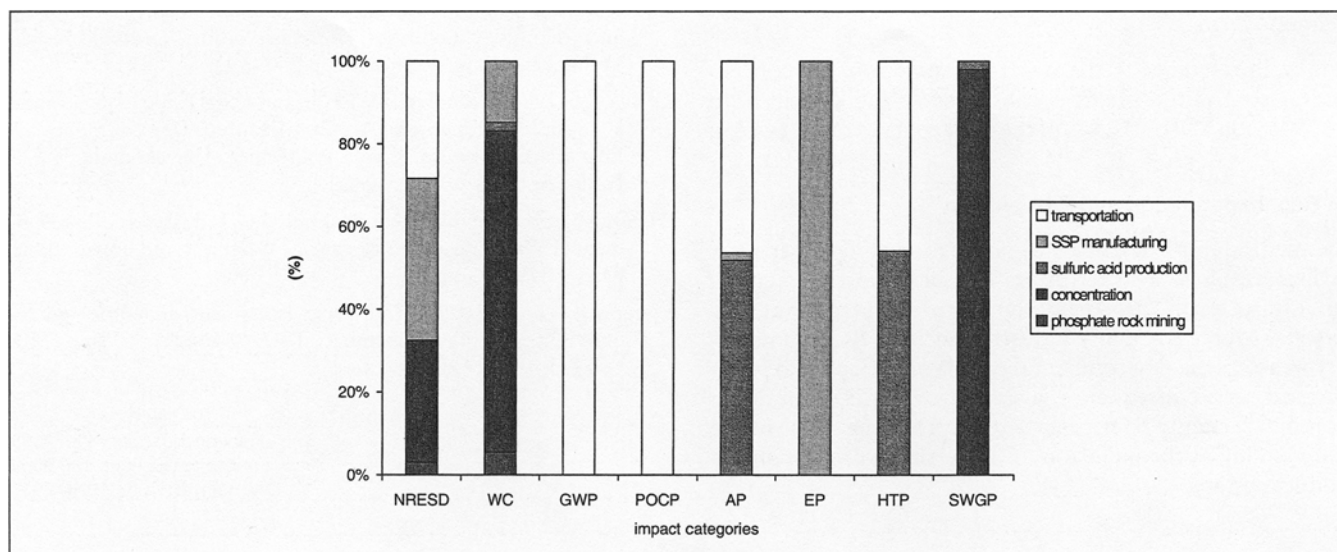


Fig. 2: Environmental profile from the SSP production

The environmental impacts associated with the transportation stage as identified in the LCA study were NRERD, GWP, POCP, AP and HTP.

The transportation of the rock from the mine to the concentration plant, and the phosphate concentrate to the SSP manufacturing site imply in an energetic consumption of 298 MJ/ton – 28.4% of the total. Therefore, the burning of diesel oil imply in a generation of 38.3 kg of CO₂(eq) with regard to GWP, and 0.023 kg of C₂H₄(eq) to the POCP. This stage of the process still has a contribution of 46.3% to the acidification as a function of the emissions of NO_x and SO₂. The release of these same compounds together with CO results to a contribution of 46% in the total HTP generated by the system.

4 Conclusion

The accomplishment of an LCA to SSP production identified in global warming and eutrophication as its meaningful environmental impacts. In reference to global warming, the transportation by road of raw materials and products was identified as the highest contributing agent with regard to this environmental impact.

Concerning eutrophication, the loss of PO₄⁻ from the SSP manufacturing can be pointed out as the main cause of contribution. In terms of photochemical oxidation and acidification, however, the results were considered satisfactory.

Concerning solid wastes, the production of a ton of SSP generates about 3.7 tons of refuse in the form of accessory ores. Although this material doesn't cause ecotoxicity problems, the form it is disposed in, outdoor of the mine, thus implying a reduction of physical space in its surroundings.

The consumption of energetic resources of the system was 1,048 MJ/ton SSP. From this amount, 750 MJ – or 71.6% – are consumed as electrical energy, and the remaining 298 MJ/ton SSP related to the burning of fossil fuel during the transportation step. Therefore, it is still important to emphasize that the sulfuric acid production step is self sufficient in energetic terms.

Finally, in reference to the water consumption, the concentration step is the greatest consumer of the system with 7,477 kg/ton SSP or 77.5% of the total demand of the system.

5 Recommendation and Perspective

The method applied can be used for modelling other LCA fertilizer studies. The fertilizers are an important item of agricultural production, and agriculture is a relevant raw material source for many industrial sectors. So, it is necessary to assess the environmental profile of agricultural products and, as a consequence, also that of fertilizer. In doing so, it will certainly be necessary to improve the scope of the study aiming at the inclusion of the fertilizer-use step in the product system.

As most of the agricultural raw materials are transferred among different countries, comparisons of the environmental profiles of fertilizers in developed and developing countries are needed.

The results of this LCA study should be extended to improve the environmental performance of the SSP production life cycle.

This study's product system is considered the production of sulfuric acid using natural elemental sulfur. An assessment of the differences in environmental performance, when recovered sulfur is used, is recommended.

The quality requirements for the phosphate rock used in the thermal and in the wet routes are quite different. This difference is likely to alter the environmental profile of the fertilizers and, thus, should also be included in future studies.

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